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ASSESSMENT OF WATER QUALITY OF THE DANUBE RIVER USING WATER QUALITY INDICES TECHNIQUE

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Abstract

In this paper, six different water quality indices were selected to assess the water quality for different uses and to identify the suitability of the selected indices in the assessment of the Danube River through a comprehensive comparison, in addition, to provide information on the spatial and temporal variations of the river water quality. The selected water quality indices are the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Oregon Water Quality Index (OWQI), Aquatic Toxicity Index (ATI), Universal Water Quality Index (UWQI), Overall Index of Pollution (OIP) and the Bascaron Water Quality Index (BWQI). Water quality dataset of 13 parameters obtained from 4 sampling points during a one-year monitoring period was considered in this study. The results demonstrated that the CCME WQI gave reasonable results in comparison to the raw data of the Danube River. The results of the other indices did not introduce representative outcomes of the raw data of the river. It was observed that some of these indices were biased and others have an eclipsing problem. However, these indices may be applicable to other water bodies.

Key words: Danube river, Drobeta-Turnu Severin, water quality assessment, water quality indices

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1. Introduction

One of the conventional ways of water quality assessment is based on the comparison of an observed value of a variable, in a water sample, with an available reference guideline of that variable. In order to assess the quality of river water, a lot of variables are required to be determined. The tabulation and interpretation processes of these variables are sometimes difficult even for the specialists in the water field (Collivignarelli et al., 2018; Pesce and Wunderlin, 2000). Moreover, it does not always provide a complete insight and integrated concept of the water quality status (Espejo et al., 2012; Kannel et al., 2007; Taseli, 2017). Thus, many tools have been applied to overcome this problem such as water quality indices (WQIs).

A first numerical WQI model was developed in 1965 by (Horton, 1965) based on 8 parameters. After Horton index, a lot of indices have been developed over the world by different institutions and authors. For example but not limited to, the developed water quality indices between the 1970s and 1980s are the National Sanitation Foundation Water Quality Index (NSFWQI) (Brown et al. 1973), the original Oregon Water Quality Index (OWQI), Prati's Index (Prati et al., 1971), Dinius' Index, Walskie-Parker index (Walski and Parker, 1974) and Bascaron WQI (Bascaron, 1979). Certain water quality indices were developed between the 1980s and 1990s such as Environmental Quality Index (EQI) (Steinhart et al., 1982), Bhargava's Index (Bhargava, 1983) and Second Dinius' Index (Dinius, 1987). In 1990, the most significant index was developed by Smith

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(1990). This index can be applied to four water uses (general, fish spawning, water supply and bathing). Another index called the Aquatic Toxicity Index (ATI) developed by Wepener et al. (1992) to assess the health of aquatic ecosystems. The most popular indices that have been developed in the 21 century: the modified Oregon Water Quality Index (OWQI) (Cude, 2001), the Environment Water Quality Index (CCME WQI), Overall Index of Pollution (OIP) (Sargaonkar and Deshpande, 2003) and Universal Water Quality Index (UWQI) (Boyacioglu, 2007). A detailed description of the aforementioned indices can be found in Abbasi and Abbasi (2012).

The main advantages of WQIs which have been stated in the previous technical reports are (Kannel et al., 2007; Massoud, 2012; Tyagi et al., 2013; Mostafaei 2014).

- Express the water quality for possible uses of a given water body in a simple way.
- Provides information on the spatial and temporal evolution of water quality in a water body which can be helpful for the managers and decision makers.
- Easily understandable for water managers and especially for non-specialist in the water field where a large amount of complex water quality data can be transformed into a single number.
- Provide a good basis for the selection of suitable water treatment method to meet the concerned issues.

However, WQIs have some disadvantages such as the limited number of variables that are considered for calculating the overall index and eclipsing problem due to the inefficient aggregation methods used (i.e. some information can be lost in the process of the index calculation which makes the final WQI does not speculate the poor quality of some parameters that may have environmental or human health importance). Additionally, certain water quality parameters have an unequal effect on the value of the WQI, resulting in a biased index (Abbasi and Abbasi, 2012; Espejo et al., 2012; Massoud, 2012; Sim et al., 2015). The major steps of WQI are (Shah and Joshi, 2015):

1. Selection of water quality parameters to be analysed,
2. Analysis/measurement of each selected water quality parameter,
3. Transform the measurement of water quality parameters into a dimensionless number using sub-index and represent them on a common scale,
4. Giving a weightage to each water quality parameter,
5. Aggregation of sub-indices to obtain the final WQI value.

The sub-indices (step 3) can be classified into four major types: linear, nonlinear, segmented linear and segmented nonlinear (Abbasi and Abbasi, 2012). In some indices, step 4 is not included in the calculations of WQI. Moreover, the final step (step 5) can be calculated using different methods such as additive aggregation (e.g. arithmetic mean), multiplicative aggregation (e.g. geometric mean), logical aggregation (e.g. minimum operator of smith index), and a combination of operations (e.g. square root harmonic means). Numerous indices have been developed on the basis of additive aggregation function such as (Horton, 1965), multiplicative aggregation (Bhargava, 1985; Brown et al., 1973; Dinius, 1987), logical aggregation (Smith, 1990), and the combination of operations (Cude, 2001; Dojlido et al., 1994).

In this paper, six popular WQIs have been used to investigate the usefulness of these WQIs in evaluating the water quality of Danube River, to identify the effectiveness of the selected WQIs through a comprehensive comparison, and to get information on the spatial and temporal variations of water quality in a simple and easy manner. The selected WQIs are CCME-WQI, OWQI, ATI, UWQI, OIP and BWQI.

2. Materials and method

2.1. Study area and water quality data

The Danube River is divided into 3 main segments: the upper Danube course (1060 km), the middle Danube course (725 km) and the lower Danube course (1075 km). The lower Danube course represents Romania's natural border with Serbia, Bulgaria, Ukraine and the Republic of Moldova (Gâştescu and Ţuchiu, 2012). In the lower course, the river is flowing through Baziaş and Gura Văii passing the Iron Gate I (14 km upstream of Drobeta-Turnu Severin city). The Iron Gate I was constructed in 1971 and considered as the largest dam and reservoir system on the basis of volume, area and hydropower potential among numerous impoundments on the Danube and the tributaries (Teodoru and Wehrli, 2005). Drobeta-Turnu Severin is a city in Mehedinți County, Romania, on the left bank of the Danube, below the Iron Gates. The city administers three villages: Gura Văii, Dudașu Schelei, and Schela Cladovei (Fig. 1).

This study covers almost 13 km of the Danube River starting at Gura Văii, 2 km downstream of Iron Gate I, and extends to Drobeta-Turnu Severin city. Two major groups of industries exist in the region: southwest industrial area (upstream of Drobeta-Turnu Severin city), and southeast industrial area (downstream of Drobeta-Turnu Severin city) (Andrița, 2012; Muntean and Morariu, 2014). In addition to agricultural practices from the Serbian part that use fertilizers and pesticides and discharged to the river through surface runoff (Gavrilescu, 2011).

In this study, a water quality data sets of 13 parameters collected at monthly intervals and obtained during 1 year at four sampling location, namely Gura Văii (SS1), Dudașu Schelei (SS2), Schela Cladovei (SS3), Drobeta-Turnu Severin (SS4) were subjected to different WQIs such as CCME WQI, OWQI, ATIWQI, UWQI, OIP and BWQI. The water quality constituents (13 parameters) are water temperature (T), hydrogen ion (pH), dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonium (NH_4), total phosphorous (TP), nitrate (NO_3^-), total suspended solids (TSS), cadmium (Cd), copper (Cu), nickel (Ni), chromium Cr) and lead (Pb). pH and T were analyzed in situ using the corresponding portable electronic device. BOD and DO were measured using Winkler azide method. TSS was analyzed by Gravimetric method, whereas NH_4, NO_3^- and TP were measured using Spectrophotometric technique. The selected heavy metals (i.e. Ca, Cr, Ni, Cu and Pb) were determined using Flame atomic absorption spectrophotometer. Table 1 shows the European Community (EC) standards (Tebbutt, 1998) for surface water quality used for drinking water abstraction. Table 2 shows the analytical results for the four sampling stations in the study area.

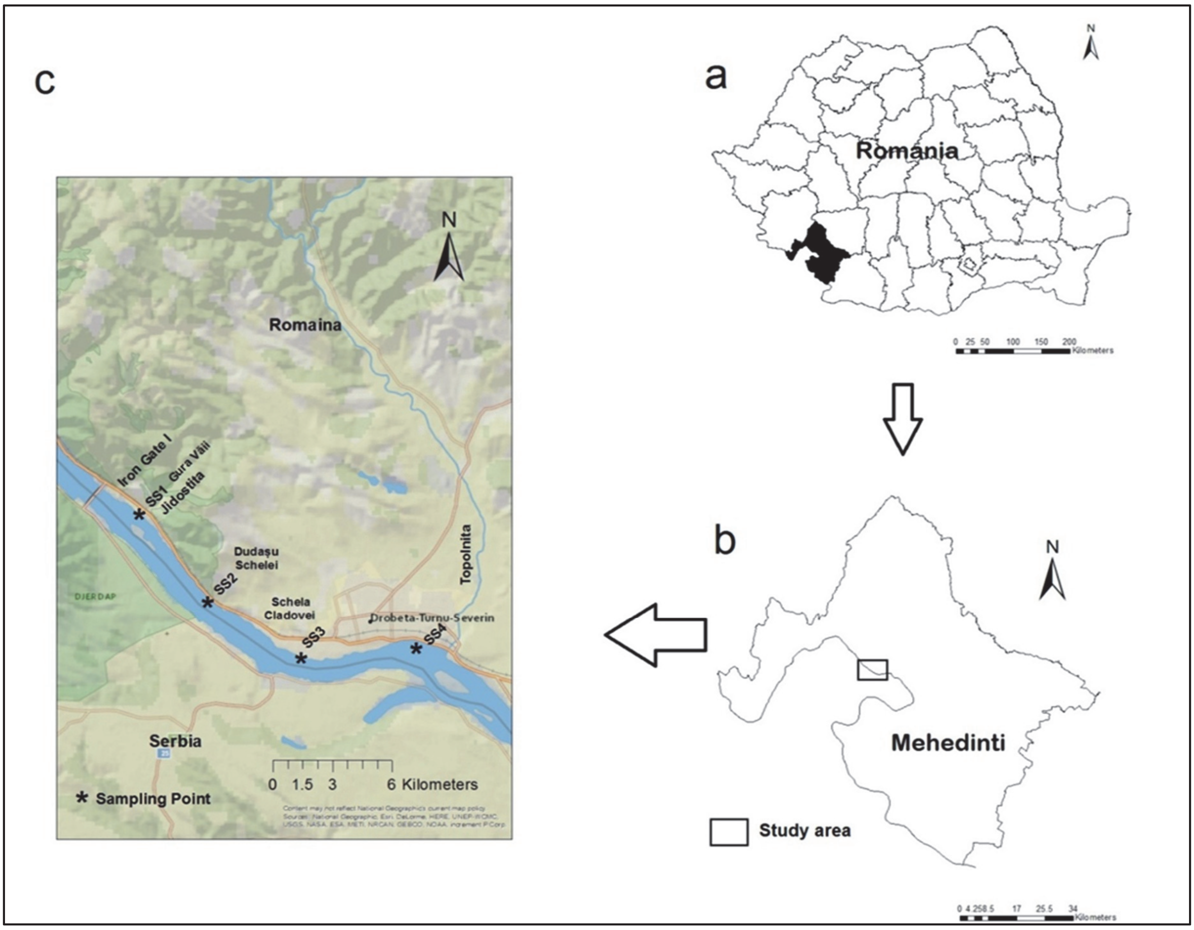

Fig. 1. Map of the study area: a) Romanian Counties, b) Mehedinţi County and c) Sampling Locations

Table 1. The European Community (EC) standards for surface water quality used for drinking water abstraction.

Parameters	*Units*	*EC standards (Guide Level)*
DO	mg/L	>4
BOD	mg/L	<3
NH_4	mg/L	0.05
NO_3^-	mg/L	25
TP	mg/L	0.1[b]
T	˚C	22
pH	-	6.5-8.5
TSS	mg/L	25
Ca	µg/L	1
Cu	µg/L	20
Cr	µg/L	50[c]
Ni	µg/L	50[b]
Pb	µg/L	50[c]

[a]directive 76/464/EEC (Tebbutt, 1998), [b]National Administration of Romanian Waters (Bălănescu, 2009), [c] maximum allowable concentration

Table 2. The analytical results for the four sampling stations in the study area

Station 1 (SS1)												
Months	***Jan***	***Feb***	***March***	***April***	***May***	***June***	***July***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
DO (mg/L)	12.69	12.19	10.39	9.11	9.2	7.95	6.63	6.58	7.7	7.83	10.5	11.34
BOD (mg/L)	2.22	1.96	1.91	2.2	1.92	2.14	1.53	1.62	1.56	1.32	1.26	1.28
NH_4 (mg/L)	0.258	0.181	0.181	0.165	0.119	0.149	0.181	0.132	0.251	0.234	0.213	0.187
NO_3 (mg/L)	3.31	1.526	2.06	1.549	1.391	3.46	1.616	1.915	1.232	2.434	2.567	2.231
Total P (mg/L)	0.145	0.22	0.42	0.43	0.31	0.22	0.31	0.27	0.74	0.53	0.33	0.31
T (°C)	5	4.5	8.5	11	19	23	23	24	21	17	15	9
pH	7.6	7.4	7.3	7.3	7.4	7.5	7.3	7.6	7.7	7.6	7.4	7.5
TSS (mg/L)	26	25	24	25	26	27	27	25	28	31	34	29
Cd (µg/L)	0.15	0.11	0.27	0.27	0.24	0.17	0.23	0.25	0.42	0.29	0.35	0.36
Cu (µg/L)	1.6	1.5	3.2	3.9	3.1	1.7	1.9	1.5	1.5	2.4	1.8	2.0
Cr (µg/L)	1.4	1.5	1.6	3.2	2.9	2.8	1.6	1.8	1.7	1.6	1.7	1.9
Ni (µg/L)	1.1	1.2	1.3	1.4	1.5	1.7	1.5	1.3	1.4	1.2	1.8	1.7
Pb (µg/L)	0.9	0.8	1.0	1.3	1.4	1.3	1.2	1.1	1.8	1.7	1.8	1.9
Station 2 (SS2)												
DO (mg/L)	12.58	12.18	9.69	8.72	8.03	5.61	7.65	6.38	7.26	7.83	9.23	11.78
BOD (mg/L)	1.54	1.95	2.04	1.99	2.37	1.21	1.3	1.52	1.53	1.45	1.35	1.39
NH_4 (mg/L)	0.266	0.212	0.173	0.172	0.157	0.154	0.282	0.087	0.165	0.134	0.183	0.174
NO_3 (mg/L)	3.49	1.865	2.107	1.46	1.216	1.775	1.481	1.465	1.232	2.387	0.211	3.311
Total P (mg/L)	0.132	0.22	0.3	0.44	0.44	0.23	0.5	0.32	0.86	0.65	0.32	0.28
T (°C)	5.8	5	10	12	21	23.5	27	24	23	18	14	10
pH	7.7	7.5	7.5	7.4	7.4	7.5	7.2	7.2	7.3	7.4	7.4	7.6
TSS (mg/L)	27	23	24	24	26	27	26	27	28	31	33	29
Cd (µg/L)	0.16	0.15	0.31	0.29	0.25	0.27	0.34	0.31	0.44	0.30	0.32	0.32
Cu (µg/L)	1.8	1.7	3.1	4.0	2.9	1.9	1.8	1.7	2.1	2.2	1.7	1.9
Cr (µg/L)	1.5	1.6	1.6	3.0	2.8	2.5	1.8	1.7	1.8	1.7	1.9	1.9
Ni (µg/L)	1.2	1.2	1.5	1.5	1.4	1.5	1.7	1.6	1.5	1.4	1.3	1.8
Pb (µg/L)	0.8	0.7	1.1	1.2	1.4	1.3	1.3	1.1	1.7	1.8	1.8	1.9
Station 3 (SS3)												
DO (mg/L)	12.32	12.18	9.62	8.83	8.62	6.57	6.8	6.46	7.34	8.42	9.56	11.56
BOD (mg/L)	1.7	1.69	1.88	2.02	1.5	1.52	1.26	1.59	1.77	1.63	1.38	1.32
NH_4 (mg/L)	0.274	0.188	0.196	0.144	0.149	0.149	0.173	0.522	0.204	0.194	0.173	0.148
NO_3 (mg/L)	3.402	1.955	2.206	1.578	1.494	3.614	1.404	1.642	1.029	2.458	2.445	3.312
Total P (mg/L)	0.135	0.21	1.44	0.48	0.32	0.2	0.76	0.86	1.05	0.58	0.39	0.21
T (°C)	5	4.9	9.6	12	20	23	25	24	22	17	15.5	8
pH	7.3	7.5	7.2	7.7	7.4	7.4	7.5	7.2	7.5	7.4	7.3	7.4
TSS(mg/L)	24	23	24	26	21	22	24	27	28	31	30	25
Cd (µg/L)	0.20	0.19	0.27	0.29	0.33	0.29	0.32	0.31	0.41	0.39	0.33	0.33
Cu (µg/L)	2.0	2.1	3.5	3.9	2.9	2.3	1.9	1.7	1.6	1.8	1.7	1.5
Cr (µg/L)	1.6	1.8	1.7	2.8	2.7	2.4	1.9	1.6	1.7	1.5	1.6	1.7
Ni (µg/L)	1.2	1.1	1.3	1.5	1.4	1.3	1.2	1.7	1.6	1.5	1.3	1.4
Pb (µg/L)	0.9	0.7	1.3	1.4	1.5	1.3	1.2	1.4	1.6	1.8	1.7	1.7
Station 4 (SS4)												
DO (mg/L)	12.53	12.18	9.9	8.89	8.62	6.71	7.03	6.47	7.43	8.8	9.88	11.89
BOD (mg/L)	1.82	1.87	1.94	2.07	1.93	1.62	1.36	1.58	1.62	1.51	1.44	1.15
NH_4 (mg/L)	0.266	0.194	0.183	0.16	0.142	0.151	0.212	0.31	0.207	0.196	0.178	0.166
NO_3 (mg/L)	3.401	1.782	2.124	1.529	1.367	2.95	1.5	1.674	1.164	0.195	0.238	3.187
Total P (mg/L)	0.137	0.217	0.72	0.45	0.357	0.217	0.523	0.483	0.883	0.47	0.38	0.19
T (°C)	5.1	4	8.5	11.5	20	24	25	24	22	19	15	10
pH	7.3	7.5	7.4	7.4	7.3	7.5	7.7	7.6	7.6	7.5	7.2	7.1
TSS (mg/L)	26	25	24	26	23	22	24	27	25	31	29	30
Cd (µg/L)	0.19	0.22	0.25	0.23	0.25	0.29	0.31	0.27	0.35	0.28	0.30	0.24
Cu (µg/L)	1.7	1.8	2.8	3.4	1.8	2.1	1.7	1.7	1.6	1.5	1.7	1.9
Cr (µg/L)	1.5	1.9	1.9	3.5	2.9	2.1	1.9	1.7	1.8	1.6	1.6	1.8
Ni (µg/L)	1.1	1.3	1.4	1.7	1.7	1.4	1.5	1.5	1.6	1.4	1.3	1.7
Pb (µg/L)	1.1	0.9	1.1	1.2	1.6	1.7	1.5	1.3	1.8	1.7	1.4	1.5

2.2. Selected WQIs Models: CCME WQI

The CCME-WQI was developed by the Canadian Council of Ministers of the Environment based on the formulation introduced by British Columbia Ministry of Environment. CCME-WQI index has been employed by different place all over the world to assess water quality (Espejo et al., 2012;

Lumb et al., 2006; Mostafaei, 2014; Sharma and Kansal, 2011). All the water quality parameters were included in the calculation of CCME-WQI, it calculated using (Eq. 1):

$$CCME - WQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \quad (1)$$

where F_1 (Factor 1) is known as the scope and, F_2 (Factor 2) is known as frequency and F_3 (Factor 3) is known as amplitude. F_1 (scope) is calculated using (Eq. 2):

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \quad (2)$$

The number of failed variables represents the percentage of variables which exceed the allowable limit value at least once during the monitoring period, relative to the total number of measured variables. F_2 (frequency) is calculated using (Eq. 3):

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}} \right) \times 100 \quad (3)$$

The number of failed tests represents the percentage of individual tests that exceed the allowable limit value, relative to the total number of tests conducted during the monitoring period. F_3 (amplitude) can be calculated in 3 steps:

1. The calculation of the excursion, Eqs. (4 and 5)

$$\text{excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_i} \right) - 1 \quad (4)$$

$$\text{excursion}_i = \left(\frac{\text{Objective}_i}{\text{Failed test value}_i} \right) - 1 \quad (5)$$

Excursion represents the number of times that the value of the variable exceeds the allowable limit value (objective). Eq. 4 is used if the value of a variable must not be greater than the allowable limit value such as BOD. Whereas, Eq. 5 is used if the value of a variable must not be less than the allowable limit value such as DO.

2. Evaluation of normalized sum of excursions (nse), (Eq. 6):

$$\text{n}se = \left(\frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Total number of tests}} \right) \quad (6)$$

where:

nse is the ratio of the sum of excursions obtained for individual tests dividing by the total number of tests (both meeting and not meeting the objective values).

3. The last step is the calculation of F_3, (Eq. 7):

$$F_3 = \left(\frac{nse}{0.01\text{nse} + 0.01} \right) - 1 \quad (7)$$

The calculation of CCME WQI value in each station has been determined by Eq. 1 in order to produce a value between 0 and 100. Then, water quality is ranked in the following categories (CCME, 2001):

- Excellent: (CCME WQI values 95–100);
- Good: (CCME WQI values 80–94);
- Fair: (CCME WQI values 60–79);
- Marginal: (CCME WQI values 45–59);
- Poor: (CCME WQI values 0–44) (Dede et al., 2013; Espejo et al., 2012; Lumb et al., 2006; Lumb et al., 2011; Mostafaei, 2014; Sharma and Kansal, 2011)

The modified Oregon Water Quality Index (OWQI)

The original Oregon Water Quality Index (OWQI) has been developed in the 1970s. Subsequent modifications have been introduced to improve OWQI method (Dunnette, 1979; Cude, 2001). This index integrates the measurement of eight parameters to produce the overall water quality, namely DO, BOD, pH, temperature, NH_3 + NO_3, TP, TS and fecal coliform. OWQI uses the non-linear sub-indices to transform the measurement of water quality parameters. The OWQI does not examine the quality of water for specific uses; rather it reflects the water quality for general recreational use (Cude, 2001; Sarkar and Abbasi, 2006). In this study, the modified OWQI by Cude (2001) were used. The overall water quality is calculated using unweighted harmonic square mean (Eq. 8):

$$OWQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI^2}}} \quad (8)$$

where *SI* is the sub-index, *n*: number of variables.

The classifications of the water quality for OWQI scale as following

- Excellent: 90-100;
- Good: 85-89;
- Fair: 80-8;
- Poor: 60-79;
- Very Poor: 10-59.

In the present paper, the water quality variables used in this index are DO, BOD, pH, NH_3 + NO_3, TP and temperature. Moreover, the mathematical equations given in (Cude, 2001) have been used to calculate the sub-index of each selected parameter.

Aquatic Toxicity Index (ATI)

ATI was developed by Wepener et al. (1992) to assess the health of aquatic ecosystems. It takes into account the toxic effects of different physical, chemical and toxic metals on aquatic life, especially fish. The water quality variables included in ATI are pH, DO, turbidity, NH_4, TDS, F^-, K, PO_4, Zn, Mn, Cr, Cu, Pb, and Ni. This index uses non-linear sub-indices to transform the measurement of water quality variables into a value between 0 and 100. The overall water quality of ATI is calculated using unweighted additive aggregation function (Eq. 9):

$$ATI = \frac{1}{100} \times \left(\frac{\sum_{i=1}^{n} q_i}{n} \right)^2 \quad (9)$$

where *qi* is the quality of the *ith* parameter (a sub-index value between 0 and 100) and *n* is the number of water quality variables included in the calculation. The classifications scheme of ATI is:

- Suitable quality for all fish life: 60-100;
- Suitable only for hardy fish species quality for all fish life: 51-59;
- Totally unsuitable for normal fish life: 0-50.

In this study, only seven water quality parameters were selected, namely pH, DO, NH_4, Cr, Cu, Pb, and Ni. Moreover, the mathematical equations are given in Wepener et al. (1992) have been used to calculate the sub-index of each selected variable.

Universal Water Quality Index (UWQI)

UWQI was proposed by Boyacioglu (2007) to assess the quality of surface water for drinking water abstraction. Various water quality standards were considered in developing this model such as the Council of the European Communities (EC, 1991) and Turkish water pollution control regulation. It includes 12 water quality parameters to calculate the final index (viz. pH, DO, NO_3, BOD, As, F^-, TP, Hg, Se, Cyanide, Cd, and total coliform). Mathematical equations were formulated for each parameter in order to determine the sub-index value. Furthermore, a weight assigned to each parameter according to its importance ranged from 1 - 4 and the overall water quality of UWQI is calculated using the weighted sum method (Eq. 10):

$$UWQI = \sum_{i=1}^{n} w_i I_i \quad (10)$$

where *wi* is a weight for *i*th variable and *Ii* sub-index for the *i*th variable. The following is the categorization scheme of UWQI

- Excellent: 95-100;
- Good: 75-94;
- Fair: 50-74;
- Marginal: 25-49;
- Poor: 0-24.

In this study, the parameters included in the calculation of UWQI are pH, DO, NO_3, BOD, TP, and Cd. The mathematical equations are given in Boyacioglu (2007) have been used to calculate the sub-index of each selected variable.

Overall Index of Pollution (OIP)

OIP was developed by Sargaonkar and Deshpande (2003) in India to assess the surface water quality. OIP took into consideration standards from various national and international agencies such as Central Pollution Control Board (CPCB), the European Community (EC), WHO and others. The water quality variables included in OIP index are color, pH, turbidity, DO, BOD, hardness, TDS, total coliforms, Cl^-, NO_3, SO_4, As, and F^-. It uses the segmented non-linear sub-indices for most of the variables to transform the measurement of water quality variables into a unitless value ranged from 1 to 16. The index scale of OIP is differing from all other water quality indices used in this study. The overall index of pollution is calculated using (Eq. 11):

$$OIP = \frac{1}{n} \sum_{i=1}^{n} p_i \quad (11)$$

The classification scheme of OIP is given below

- Excellent: 0-1;
- Acceptable: 1-2;
- Slightly Polluted: 2-4;
- Polluted: 4-8;
- Heavily Polluted: 8-16.

For comparison purpose, the index scale of OIP has been adjusted from 0 -16 to 0-100 which becomes (Dede et al., 2013):

- Excellent: 94-100;
- Acceptable: 87.5-94;
- Slightly Polluted: 75-87.5;
- Polluted: 50-75;
- Heavily Polluted: 0-50.

In this study, only four parameters were considered to produce the final OIP index, namely pH, DO, BOD, and NO_3. The mathematical equations are given in Sargaonkar and Deshpande (2003) were used to calculate the sub-index for the individual parameter.

Bascaron WQI (BWQI)

The Bascaron WQI (BWQI) came from Spain (Bascaron, 1979) and has been widely used over the world (Debels et al., 2005; Kannel et al., 2007; Massoud, 2012; Pesce and Wunderlin, 2000). The overall index is being estimated as subjective water quality index (Eq. 12):

$$WQI_{sub} = k \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \quad (12)$$

where n = the total number of variables, C_i = value assigned to the variable i after normalization, P_i = relative weight assigned to each variable which ranged from 1 to 4 according to its influence on the water quality (4 for highest impact and 1 for less impact) , k = subjective constant identified by the visual impression of river contamination. The values of k may be 0.25, 0.5, 0.75, or 1. The basic criteria to select one of these values have been given in Pesce and Wunderlin (2000). However, in this study, the value of k was adopted as 1 to account only for the variations due to measured variables (Kannel et al., 2007; Pesce and Wunderlin, 2000), (Eq. 13):

$$WQI_{sub} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \quad (13)$$

The major advantage of BWQI is that a large number of water quality variables can be included in calculating the final index after assigning the normalization factors as well as their weights. However, only 22 water quality parameters were found that already have been normalized and weighted in previously reported studies (Kannel et al., 2007; Massoud, 2012; Pesce and Wunderlin, 2000). In the present paper, eight water quality parameters were included in the evaluation process, namely temperature, pH, DO, BOD, NH_4, NO_3, TP, and TSS. The normalization factors along with their weights given in Table 3 were used for the selected parameters to produce the final BWQI. The following classification scheme was adopted to classify the water quality (Dojlido et al., 1994):

- Excellent: 90-100
- Good: 71-90
- Medium: 51-70
- Bad: 26-50
- Very bad: 0-25

4. Results and discussion

In order to interpret the water quality data in an easy and understandable way, different water quality indices have been used such as CCME WQI, OWQI, ATI, UWQI, OIP, and BWQI. Moreover, the comparison between the results of the selected indices is also presented in this study.

The results of CCME WQI are shown in Table 4. The European Community (EC) standards for drinking water abstraction were used for CCME WQI calculation and presented in Table 1 (Tebbutt, 1998). In CCME-WQI, all the variables were taken into consideration for the calculation process. The water quality classification scheme for sampling stations was found fair in all stations. The most important variables that affect the water quality were NH4, TP, T, and TSS.

The sub-index values alongside the final results of OWQI and categorization are presented in Table 5. The water quality categorization for all sampling sites was found as very poor. A significant change of OWQI values was observed in Feb (all stations) and June (2 stations). In OWQI, the major parameters that affect the water quality are NO_3 and TP.

The calculated sub-index values of ATI with the overall index and its categorization are shown in Table 6. ATI was used to assess the health of aquatic life, especially fish, in the river. The classification scale of the water quality for all sampling sites suggests that the river is suitable quality for all fish life. Furthermore, no significant temporal variation was observed for all stations and NH_4 was the major important parameter in this index.

In the universal water quality index (UWQI), six parameters were used. The calculated sub-index values along with the weight factors for each parameter, the overall UWQI and the water quality categorization are given in Table 7. The water quality categorization for all sampling sites was found as good. Excellent water quality was observed in the month of January for all sampling stations. Total P was the prominent parameter in this index.

Table 3. The normalization factors along with their weights for the selected water quality parameters (Kannel et al., 2007; Massoud, 2012; Pesce and Wunderlin, 2000).

Variables	*Unit*	*Relative Weight (Pi)*	*Normalization Factor (Ci)*										
			100	*90*	*80*	*70*	*60*	*50*	*40*	*30*	*20*	*10*	*0*
T	˚C	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/−2	40/−4	45/−6	>45/<−6
pH	-	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	2-12	2-13	1-14
DO	mg/L	4	>=7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	>=1	<1
TSS	mg/L	4	<20	<40	<60	<80	<100	<120	<160	<240	<320	<400	>400
TP	mg/L	1	<0.2	<1.6	<3.2	<6.4	<9.6	<16	<32	<64	<96	<160	>160
NH_4	mg/L	3	<0.01	<0.05	<0.1	<0.2	<0.3	<0.4	<0.5	<0.75	<1	<=1.25	>1.25
NO_3	mg/L	2	<0.5	<2	<4	<6	<8	<10	<15	<20	<50	<=100	>100
BOD	mg/L	3	<0.5	<2	<3	<4	<5	<6	<8	<10	<12	<=15	>15

Table 4. The calculated *F* factors of CCME-WQI index

Stations	*F1*	*F2*	*F3*	*CCME-WQI*	*Categorization*
SS1	30.7	26.0	39.4	67.5	Fair
SS2	38.5	26.9	40.1	64.3	Fair
SS3	30.7	23.7	44.7	65.8	Fair
SS4	30.7	24.3	41.3	67.1	Fai

Table 5. The results of OWQI index

Stations	*Sub-index values*							
	DO	*BOD*	*NO_3*	*Total P*	*Temp.*	*pH*	*OWQI*	*Categorization*
SS1	89.71	70.82	37.88	17.90	85.07	100	26.04	Very Poor
SS2	85.93	72.33	44.57	17.97	80.24	100	27.63	Very Poor
SS3	87.52	72.69	35.98	21.15	82.91	100	26.01	Very Poor
SS4	88.52	71.94	47.17	21.01	81.84	100	27.88	Very Poor

Table 6. The results of ATI index

Stations	*Sub-index values*								
	DO	*NH_4*	*pH*	*Cu*	*Cr*	*Ni*	*Pb*	*ATI*	*Categorization*
SS1	93.08	57.46	100	100	100	100	100	86.39	Suitable quality for all fish life
SS2	90.08	58.72	100	100	100	100	100	85.93	Suitable quality for all fish life
SS3	91.70	55.79	100	100	100	100	100	85.61	Suitable quality for all fish life
SS4	92.46	56.21	100	100	100	100	100	85.91	Suitable quality for all fish life

Table 7. The results of UWQI index

Stations	*Sub-index values*							
	DO	*BOD*	*NO_3*	*Total P*	*pH*	*Cd*	*UWQI*	*Categorization*
SS1	93.10	100	100	34.09	100	100	89.57	Good
SS2	89.35	100	100	31.28	100	100	88.19	Good
SS3	89.94	100	100	25.48	100	100	87.60	Good
SS4	90.92	100	100	29.36	100	100	88.36	Good
Rating	4	2	3	2	1	3		
Weight factors	0.27	0.13	0.2	0.13	0.07	0.2		

In the overall index of pollution (OIP), sub-index calculation with the final values and categorization of the water quality are shown in Table 8. This index has a scale ranged from 0 to 16; this scale has been converted to a scale ranged from 0 to 100 for comparison purpose (Dede et al., 2013). The categorization of water quality in all stations was found as acceptable. It was observed that all the variables used in this model have the same degree of significance on water quality.

According to OIP, sub-index calculation with the final values and categorization of the water quality are shown in Table 8. This index has a scale ranged from 0 to 16; this scale has been converted to a scale ranged from 0 to 100 for comparison purpose (Dede et al., 2013). The categorization of water quality in all stations was found as acceptable. It was observed that all the variables used in this model have the same degree of significance on water quality.

The last index used in this study is the Bascaron WQI (BWQI). Table 9 shows the sub-index values, the water quality was found good in all stations. The most important parameters that affect adversely on water quality are NH_4 and T.

The selected water quality index models have different approaches in the implementation process. In this paper, CCME-WQI has a totally different approach in comparison with other selected indices. It has the following characteristics:

- the ability to take into consideration all the water quality variables,
- very flexible in the selection of water quality standards,
- tolerant in case of missing data (Terrado et al., 2010).
- Assess the water quality for different uses and does not use the sub-index to transform the measurement of water quality into a unitless number.

However, CCME-WQI considering all the water quality variables have the same degree of importance and it can be applied only when there are available guidelines on the water quality parameters.

The other water quality index models rely on sub-indices values in the calculation process with different aggregation methods. In OWQI, non-linear subindex is used and unweighted harmonic square mean function for aggregation. OWQI evaluates the general recreational use of water like fishing and swimming. The results of this index indicate that the water quality is very poor in all sampling station, despite the low values of BOD and high values of DO in the river. NO_3 and TP were the major factor affecting the water quality in this model and however, NO_3 was within the standards limit (Table 1).

Therefore, OWQI was not applicable in assessing the water quality of Danube River (study region), which resulted in bias index.

ATI accounts for some heavy metals parameters to evaluate the fish life of the river. The results revealed that the river quality is suitable for all fish life in all sampling stations. ATI is using the unweighted additive function for the aggregation process. ATI model was somewhat acceptable in spite of eclipsing problem for NH_4 value which exceeded the limits. UWQI assessing the surface water quality for drinking water abstraction. It uses the weighted sum function for the aggregation process and segmented linear sub-index. This model gives a weighting factor for each variable which makes it differ from others (i.e. the water quality variables do not have the same degree of importance). The results showed that the river water quality is good with a value of more than 87 in all stations (Table 7) in spite of very low sub-index values for TP. The weighted sum function has eclipsed the effect of TP.

In OIP, only four water quality parameters were considered for calculation the final index. This model has different scale among others and the results revealed that the river water quality is acceptable. The comparison process would be unfair because the model takes into account 13 water quality variables versus four parameters considered in this study. However, this model does not account for phosphorus compounds.

The BWQI is used to evaluate the water quality for general uses. It uses a weighted sum function for the aggregation process and segmented linear sub-index (step type). BWQI assigns a relative weight for each water quality parameters. The results showed that the river water quality is „good". The major issue in this index is that the given relative weight for each variable may be varied due to multiple perspectives of the experts. A comparison of the different water quality index models used in this study presented in Table 10.

Based on the above discussion, it can be concluded that the CCME-WQI has provided realistic results in comparison to the raw data of the Danube River. The results of CCME-WQI were fair in all stations. Fair category indicates that "the water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels" (CCME 2001). CCME-WQI has given the best results among other models. The results of the other models (OWQI, ATI, UWQI, OIP, and BWQI) did not introduce representative outcomes of the raw data of the river. Generally, no significant changes were observed for temporal variation in the Danube river water quality.

Table 8. The results of OIP index

Stations	*Sub-index values*						
	DO	*BOD*	*NO_3*	*pH*	*OIP (0-16)*	*OIP (0-100)*	*Categorization*
SS1	1.44	1.12	1.00	1.55	1.28	92.20	Acceptable
SS2	1.57	1.08	1.00	1.50	1.29	92.15	Acceptable
SS3	1.52	1.03	1.00	1.46	1.25	92.36	Acceptable
SS4	1.51	1.03	1.00	1.50	1.26	92.30	Acceptable

Table 9. The results of BWQI index

Stations	*Sub-index values*									
	DO	*BOD*	*NH_4*	*NO_3*	*Total P*	*Temp.*	*pH*	*TSS*	*BWQI*	*Categorization*
SS1	98.33	87.50	66.67	85.00	90.83	73.33	90.00	90.00	86.32	Good
SS2	95.83	88.33	68.33	87.50	90.83	72.50	90.00	90.00	86.40	Good
SS3	95.83	89.17	65.00	85.00	90.83	72.50	90.00	90.00	85.75	Good
SS4	95.83	89.17	65.83	88.33	90.83	72.50	90.00	90.00	86.23	Good
Relative weight (*P_i*)	4	3	3	2	1	1	1	4	$\sum P_i = 19$	

Table 10. Comparison between the different WQIs used in this study

WQI models	*Sub-indices for the most variables*	*Aggregation methods*	*Water uses*	*Number of variables*
CCME-WQI	Formula	Harmonic Square sum function	Various water uses	L[a]
OWQI	Non-linear	Unweighted harmonic square mean function	General recreational use	8
ATI	Non-linear	Unweighted additive aggregation function	Health of aquatic ecosystems	14
UWQI	Segmented linear	Weighted sum function	Drinking water abstraction	12
OIP	Segmented non-linear	Unweighted arithmetic mean function	Surface water quality	13
BWQI	Segmented linear (step)	Weighted sum function	General uses	22[b]

[a] Large numbers of variables can be included in the calculation of CCME-WQI but not less than four variables
[b] The available water quality variables that already have been normalized and weighted in the previous reports.

5. Conclusions

This paper comprised the use of six WQIs to assess the water quality in the Danube River. The selected WQIs have different approaches to the implementation process. The water quality of the Danube River at four sampling stations was fair for CCME-WQI, very poor for OWQI, suitable for all fish life for ATI, good for UWQI, acceptable for OIP and good for BWQI.

The CCME-WQI has provided realistic results in comparison to the raw data of the Danube River. It has a totally different approach and distinct characteristics in comparison with other selected indices. It has the ability to take into considerations all the water quality parameters. It is flexible in the selecting of the water quality standards and tolerant in case of missing data. However, this index is considers all the water quality variables have the same degree of importance, and it can be applied only when there are available guidelines on water quality parameters. The CCME-WQI can express the quality of water for different uses such as general uses, drinking water abstraction, and the health of aquatic life etc., whereas the other indices express the quality of water for specific uses only.

The other selected WQIs (OWQI, ATI, UWQI, OIP, and BWQI) rely on sub-indices values in the calculation process with different aggregation methods. ATI model was somewhat acceptable in spite of eclipsing problem for NH_4 value which exceeded the limits. OIP has a different scale in comparison to other models and the output result was acceptable in all stations.

The comparison process for OIP would be unfair because the model takes into account 13 water quality variables versus four parameters considered in this study. However, this model does not account for phosphorus compounds. UWQI and BWQI have eclipsed the effect of TP and NH_4 respectively, during the aggregation process.

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